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Electron tunneling through triple barrier structure with intersubband population inversion

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Intersubband population inversion in a GaAs/AlGaAs triple barrier structure was demonstrated recently by photoluminescence spectroscopy [1]. The maximum population ratio $n_2/n_1 \approx 5$ between $n = 1$ (E1) and $n = 2$ (E2) electron subbands of the wider quantum well (QW1) was obtained when the structure was biased so that E1 was in resonance with the $n = 1$ (E1*) level of the narrower quantum well (QW2) (see insert in Fig. 1). At this bias electrons from emitter tunnel into the E2 level. E1 electrons may escape rapidly by resonant tunneling via E1*, whilst the E2 escape time from QW1 is significantly longer, since E2 electrons must tunnel non-resonantly through a relatively wide region comprising the intermediate and collector barriers and QW2. Such structures therefore provide the short E1 lifetime necessary to achieve E2-E1 population inversion, whilst maintaining a high density of E2 electrons available for E2-E1 transition.

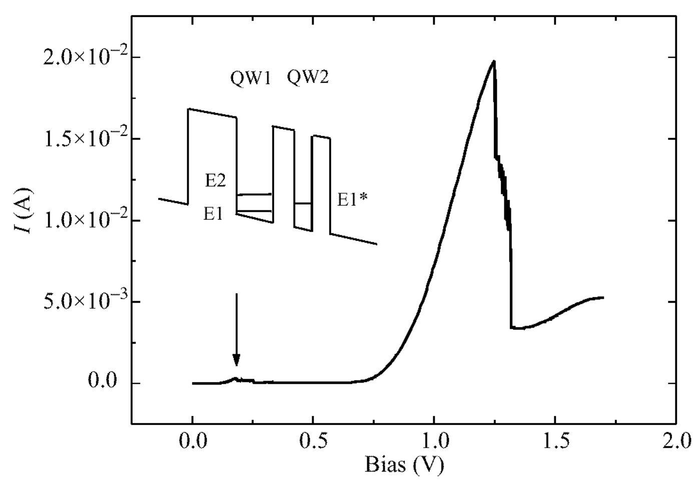

Fig 1. IV characteristics of the structure. Arrow shows the position of the resonant tunneling through E1 state. Insert demonstrates band diagram of the sturcture.

In this work we report the results of careful measurements of tunneling current on the same structures in a wide temperature range and magnetic field parallel to the QW which as expected should destroy resonance between E1 and E1* levels [2] at particular voltage bias. We found the features in IV characteristics which we interpreted as appearance of additional current channel linked with E1-E1* resonance.

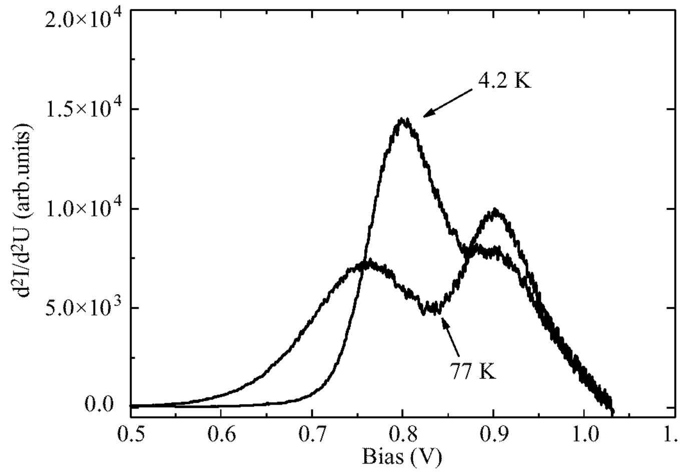

Fig 2. Second derivative of the current voltage characteristic at the region of population inversion at different temperatures: 4.2 K and 77 K.

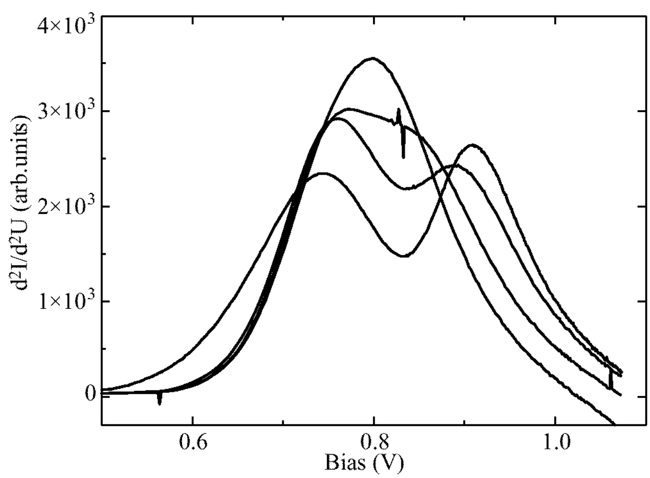

Fig 3. Second derivative of the current voltage characteristic at different in plane magnetic fields: 0 T, 1 T, 2 T, 4 T. Temperature $T = 60$ K.

The measured IV curves at 4.2 K is shown in Fig. 1. The inversion population was observed at voltage range (0.6–1.0) V with maximum located at 0.8 V [1]. Fig. 2 shows the second derivative of the current voltage characteristics. Two peaks appear at the same voltage range, which are more pronounced at 77 K, and are smeared out at 4.2 K. In control sample with wider second QW where E1-E1* resonance should appear at higher biases only one peak have been observed. As one peak is related to the main resonance tunneling through E2 state, we attribute the second peak to the appearance of the new additional current channel due to the E1-E1* resonance. These two peaks are more pronounced at 77 K, may be due to the higher efficiency of electron relaxation

from E2 to E1 level with phonon emission or absorption.

To prove proposed explanation the magnetic field was applied parallel to the QW plane at 60 K. It can be seen from Fig. 3 that magnetic field suppress two peaks picture because it change wave vector of the tunneling electrons on the way between two quantum wells due to the Lorentz force and as the result moves E1-E1* resonance to higher voltage and broaden it [3].

Thus we have found features in tunneling current which are related to the resonance between ground quantum well states in triple barrier structures when the current mainly determined by electron tunneling from emitter to the first excited state in the first quantum well.

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